

EVALUATION ON PERFORMANCE OF SQUARE FINNED CONFORMAL
COOLING CHANNEL (SFCCC) FABRICATED BY SELECTIVE LASER
MELTING (SLM) ON PLASTIC MOULDED PART

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Special dedication to my beloved parents, wife and family..... Thanks for the love,
support and memories



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ABSTRACT

In plastic injection moulding (PIM) process, the cooling stage is the most important phase because it significantly affects the productivity and quality of the molded part. Thus, the cooling system need to be emphasized in designing the injection mould system. The application of conformal cooling channels which only can be fabricated by additive manufacturing technology (AM) are proven to increase the injection moulding performance and able to reduce the quality issues. This research introduced the Square Finned Conformal Cooling Channel (SFCCC) in the PIM as a way to enhance the performance of square shape conformal cooling channel (SSCCC) in PIM. The mould insert with SFCCC has been designed, simulated via finite element analysis software, fabricated (by combination of High Speed Machining and Selective Laser Melting (SLM)), and tested using a front panel housing as the injected part for the case study. Eight types of variate SFCCC design (SFCCC 1 to SFCCC 8) employing finned and sub groove concept were analysed via simulation work to determine the best design in terms of shortest cooling time. The results showed that the shortest cooling time recorded by SFCCC 8 was at 7.621 sec, an improvement of 16.44% compared with SSCCC. In terms of cycle time, the SFCCC is able to improve the SSCCC by 8.33% to 10.26%. Meanwhile, in comparison with industrial mould using Milled Groove Conformal Cooling Channel (MGCCC), the SFCCC showed an improvement of 19.60% to 39.36% based on the coolant temperature. The experimental results showed the greatest shrinkage in the X-direction at 0.93% and the smallest shrinkage at 0.6%. For the Y-direction, the greatest shrinkage is 0.97% and the smallest shrinkage is 0.39%. In comparison with the injected part via MGCCC, the SFCCC had a slightly greater overall shrinkage in relation to the shrinkage and warpage at points X and Y direction. Most front panel housing shrinkage and warpage values in the experimental study were smaller than those of the simulative study. However, the experimental results were in line with the simulative results, proving that the SFCCC design had better cycle times and acceptable quality for an industrial mould.

ABSTRAK

Dalam proses pengacuan suntikan plastik (PIM), penyejukan merupakan fasa yang paling penting kerana ianya memberi kesan yang signifikan kepada produktiviti dan kualiti terhadap komponen yang dihasilkan. Dengan itu, tumpuan yang lebih perlu diberikan dalam merekabentuk sesebuah pengacuan suntikan. Penggunaan saluran penyejukan konformal (yang hanya boleh dihasilkan dengan menggunakan teknologi aditif (AM)) telah terbukti dapat meningkatkan prestasi proses pengacuan suntikan dan seterusnya mampu mengurangkan isu-isu berkaitan dengan kualiti. Kajian ini telah memperkenalkan penggunaan saluran penyejukan konformal bersirip berbentuk segiempat (SFCCC) di dalam proses pengacuan suntikan (PIM) yang bertujuan untuk meningkatkan prestasi saluran penyejukan konformal berbentuk segiempat (SSCCC). Acuan suntikan dengan SFCCC telah direkabentuk, disimulasi dengan perisian kaedah analisis terhingga, dihasilkan (dengan menggunakan pemesinan berkelajuan tinggi (HSM) dan pencairan laser terpilih (SLM)) dan diujilari dengan menggunakan panel perumah hadapan sebagai produk untuk kajian kes. Lapan jenis rekabentuk SFCCC yang berbeza (SFCCC 1 hingga SFCCC 8) menggunakan konsep sirip dan lurah kecil telah dianalisis dengan menggunakan simulasi bagi menentukan rekabentuk terbaik dengan mengambil kira masa penyejukan yang paling pendek. Dengan penentuan suhu penyejuk antara 25°C to 60°C, SFCCC 8 mencatatkan keputusan masa penyejukan paling pendek iaitu 7.621 saat dengan penambahbaikan sebanyak 16.44% berbanding dengan SSSCC. Untuk kitaran masa, SFCCC telah meningkatkan prestasi SSSCC di antara 8.33% hingga 10.26%. Sementara itu, perbandingan antara acuan industri yang menggunakan penyejukan konformal berbentuk segiempat alur terkisar (MGCCC) dengan acuan suntikan SFCCC pula telah menunjukkan peningkatan sebanyak 19.6% hingga 39.36% bergantung kepada suhu penyejuk. Keputusan ujikaji menunjukkan pengecutan yang paling besar berlaku pada arah-X bernilai 0.93% dan nilai paling kecil pula adalah sebanyak 0.6%. Untuk arah – Y pula, nilai pengecutan paling besar

berjumlah 0.97% dan nilai terkecil adalah sebanyak 0.39%. Perbandingan pada nilai keseluruhan bagi pengecutan dan ledingan pada komponen yang disuntik menunjukkan nilai bagi SFCCC lebih besar berbanding dengan MGCCC pada kedua-dua arah x dan y. Manakala hampir kesemua nilai pengecutan dan ledingan bagi ujikaji lebih kecil berbanding dengan nilai dari simulasi. Walaubagaimanapun keputusan ujikaji adalah selari dengan keputusan simulasi, ini membuktikan bahawa rekabentuk SFCCC mempunyai nilai kitaran masa yang lebih singkat namun tidak menjejaskan kualiti komponen yang dihasilkan.



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LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|-------|---|---|
| ABS | - | Acrylonitrile Butadiene Styrene |
| AM | - | Additive Manufacturing |
| ANN | - | Artificial Neural Network |
| ANSYS | - | Analysis System |
| CAD | - | Computer Aided Design |
| CAE | - | Computer Aided Engineering |
| CMM | - | Coordinate Measuring Machine |
| CNC | - | Computer Numerical Control |
| DMLS | - | Direct Metal Laser Sintering |
| DMT | - | Direct Metal Tooling |
| EDM | - | Electro Discharged Machining |
| FEA | - | Finite Element Analysis |
| FEM | - | Finite Element Method |
| GA | - | General Algorithm |
| MFI | - | MoldFlow Insight |
| MGCCC | - | Milled Groove Square-shaped Conformal Cooling Channel |
| MGSS | - | Milled Grooved Square Shape |
| PC | - | Polycarbonate |
| PIM | - | Plastic Injection Moulding |
| POM | - | Polyoxymethylene |
| PP | - | Polypropylene |
| RP | - | Rapid Prototyping |
| RT | - | Rapid Tooling |
| SFCCC | - | Square Finned Conformal Cooling Channels |

| | | |
|---------------------|---|---|
| SLM | - | Selective Laser Melting |
| SLS | - | Selective Laser Sintering |
| SSCCC | - | Square Shape Conformal Cooling Channels |
| VRCCC | - | Variable Radius Conformal Cooling Channel |
| STL | - | Stereolithography |
| 3DP | - | Three Dimensional Printing |
| L_{cavity} | - | Cavity length |
| p | - | Wetted perimeter of the cooling channels |
| μ | - | Dynamic viscosity of water |
| A | - | Cross-sectional area of the cooling channels |
| D_H | - | Hydraulic diameter |
| $L_{part.}$ | - | Part length |
| $Q_{molding}$ | - | Quantity of heat dissipated by the cooling system |
| $m_{molding}$ | - | Mass of the moulded part |
| C_p | - | Specific heat of injected part |
| T_{melt} | - | Melting temperature |
| T_{eject} | - | Ejection temperature |
| V_{mf} | - | Volume of the injected part |
| ρ | - | Density of the plastic material |
| $\dot{Q}_{cooling}$ | - | Cooling power |
| t_c | - | Cooling time of runner |
| α | - | Thermal diffusivity |
| $T_{coolant}$ | - | Coolant temperature |
| \dot{Q}_{line} | - | Heat transfer rate per cooling line |
| n_{lines} | - | Number of cooling lines |
| $\dot{V}_{coolant}$ | - | Coolant flow rate |
| Δ | - | Difference |
| D_{max} | - | Maximum size of the cooling channel |
| Re | - | Reynolds number |
| H_{line} | - | Distance from cooling channel to mould surface |
| \emptyset | - | Diameter |
| K | - | Thermal conductivity |

| | | |
|----------------------|---|----------------------------|
| $\sigma_{endurance}$ | - | Stress endurance |
| $\sigma_{nominal}$ | - | Nominal compressive stress |
| Pr | - | Prandtl number |
| sec | - | Second |
| mm | - | Millimeter |
| Nm^{-2} | - | Newton / meter square |
| cm^3 | - | Centimeter cubic |
| kg/hr | - | Kilogram per hour |



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